# The Development of a Water Tube Marine Boiler.

A Thesis leading to the Degree of Mechanical Engineer by

J. Rowland Brown

May 1st, 1903.

4 June '48. Ser. J. Unwin. B. J. Rowland

At the present time, the discussion of the relative advantages and disadvantages of the Scotch (tubular) and the water tube (tubulous) boilers, as applied to naval purposes, is most actively carried on by interested engineers. That the water tube boiler is gaining ground is shown by the increasing number of installations, on ships of the best design and largest size, of that type of boiler.

It is not in the province of this paper to bring out this discussion or refer to the Scotch type of boiler, but to present a particular type of water tube boiler recently invented.

Before entering into the

description of this particular type of boiler it will be necessary to state and briefly discuss the features in the design of a water tube boiler that make it suitable and efficient for naval purposes.

Every boiler whether stationary or marine must have the three merits:— durability, reliability and efficiency.

A "marine" boiler, to be successful, must possess certain features among which the following are the most essential.

(1) It must occupy a limited space. In other words the ratio of heating surface to volume must be a maximum and in practice varies from 1.5 to 2.5 square

feet of heating surface per cubic foot of volume.

(2.) It must be of minimum weight, and here is one of the chief advantages of the water tube class. The weight per square foot of heating surface must be low and in practice varies from 10 to 30 pounds per square foot of heating surface, for the empty boiler.

(3) It must be of such construction as to assure safety from disastrous explosion. That is, each part must be of sufficient strength and free from defects, but more important still the boiler must be divided and sub-divided into elements so that even though a rupture does take place it

will be local and not general, thus preventing a disastrous explosion.

14. It must be readily accessible, in all its parts, for repairs. In other words, the prompt repair of one part should not be hindered by the presence of some other part; and the repair of any part should not make necessary the renewal of any other part. The construction should be such that repairs can be made without carrying an excessively large supply of duplicate parts, and such that ordinary repairs can be made on board ship or in a foreign port. The boiler should have few special parts

that require special machinery to produce; — in other words it should be of standard construction consisting of parts that can be purchased in the open market.

(5.) It must be readily accessible for cleaning. All parts of the heating surface where soot can collect or scale form, or parts other than heating surface where loose scale can deposit and impede circulation should be so constructed that they can be cleaned without great loss of time and with a minimum of labor.

(6.) It must be of such a design as to assure a positive

uninterrupted circulation of the water throughout all its parts subjected to the action of the heated gases.
"(7) It must have the heating surface so distributed, in relation to the path of the gases, that there must result an efficient and sufficient absorption of the heat."
"Many other features might be cited, but on other points there is room for discussion as to their merits; while in the seven requirements noted above it is safe to say all engineers will agree."
The particular type of water tube marine boiler which this paper presents for your attention

No. 11,870.

Reissued Nov. 13, 1900.

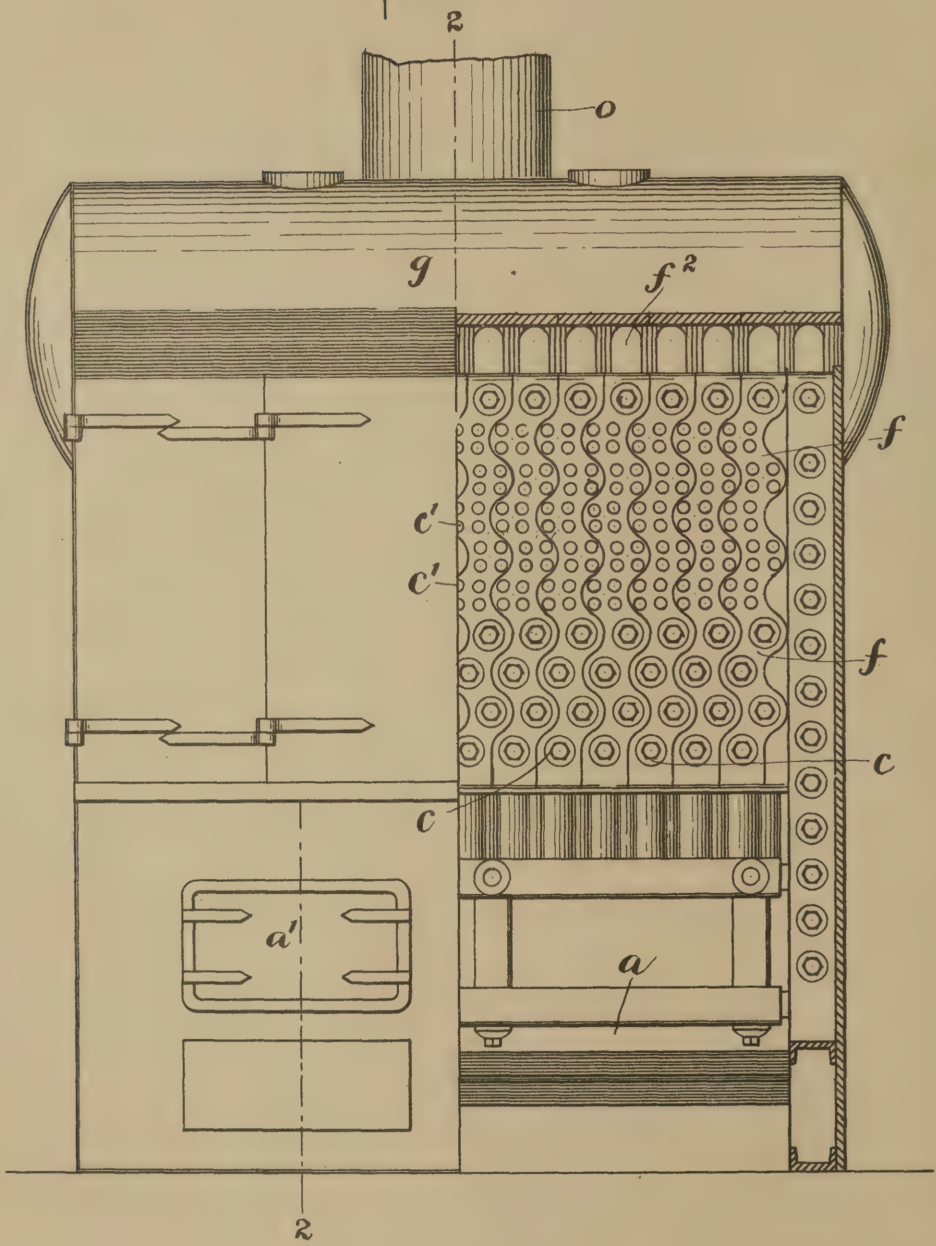
K. PARK.

STEAM GENERATOR.

(Application filed Oct. 4, 1900.)

3 Sheets—Sheet 1.

Fig. 1.

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THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

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3 Sheets—Sheet 2.

FIG. 2.

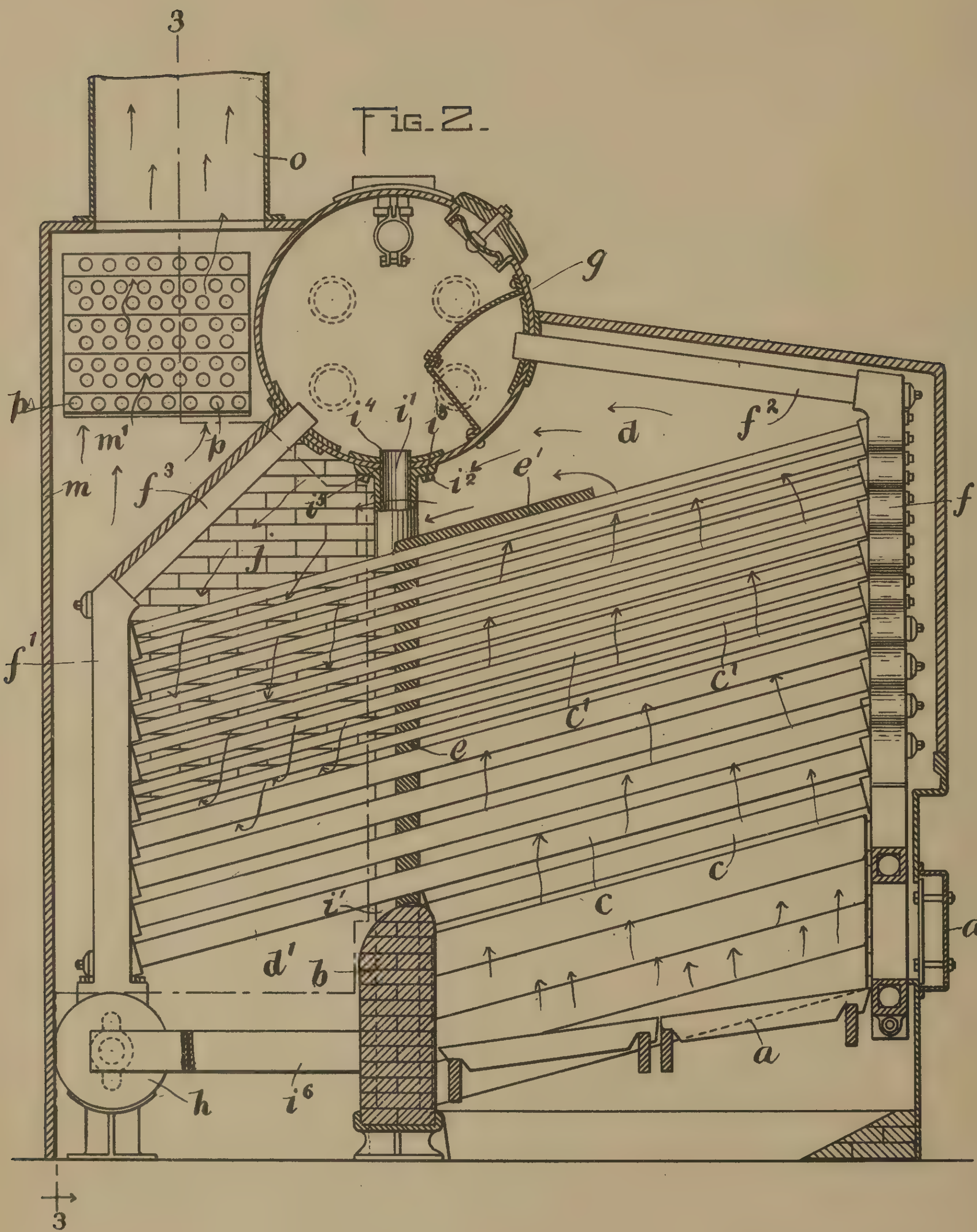


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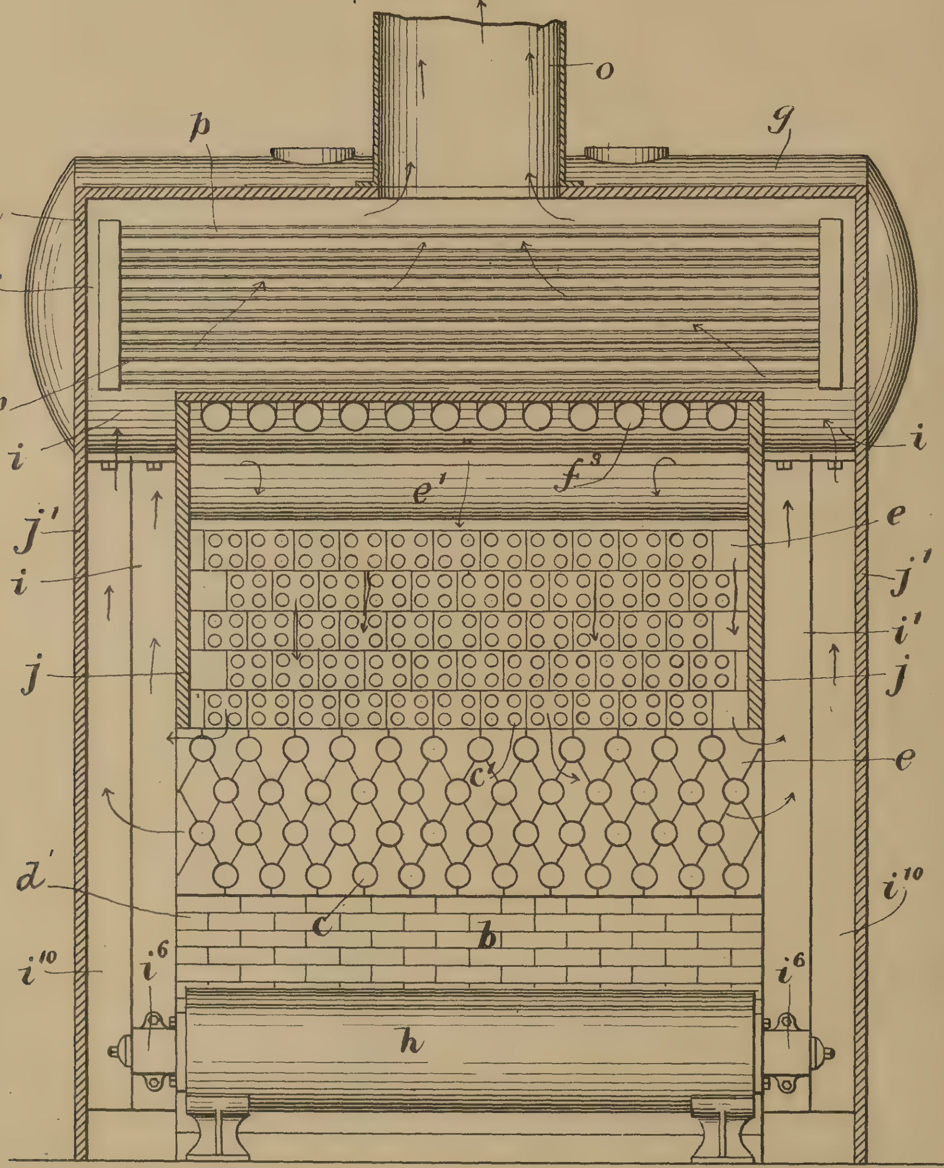
Fig. 3.

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# UNITED STATES PATENT OFFICE.

KENNEDY PARK, OF CAMBRIDGE, MASSACHUSETTS.

## STEAM-GENERATOR.

**SPECIFICATION** forming part of Reissued Letters Patent No. 11,870, dated November 13, 1900.

Original No. 627,521, dated June 27, 1899. Application for reissue filed October 4, 1900. Serial No. 32,008.

*To all whom it may concern:*

Be it known that I, KENNEDY PARK, of Cambridge, in the county of Middlesex and State of Massachusetts, have invented certain new and useful Improvements in Steam-Generators, of which the following is a specification.

This invention relates to steam boilers and generators of tubular construction a plurality of tubes being arranged over the fire-box and connected at their ends with headers which communicate with the steam and water drums.

The invention has for its object to provide a steam-generator of this type which shall be of compact construction, the tubes being of such length as to enable the apparatus to be conveniently used on steam-yachts and other relatively small navigable vessels, the generator being at the same time constructed so as to utilize as fully as possible the efficiency of the fire.

The invention consists in the improvements which I will now proceed to describe and claim.

Of the accompanying drawings, forming a part of this specification, Figure 1 represents a front elevation of a steam-generator embodying my invention, a part of the casing being removed. Fig. 2 represents a section on line 2 2 of Fig. 1. Fig. 3 represents a section on line 3 3 of Fig. 2.

The same letters of reference indicate the same parts in all the figures.

I have shown my invention embodied in a steam-generator having two fire-boxes, each having a grate $a$ and fire-doors $a'$.

$b$ represents the bridge-wall, which forms the rear end of each fire-box.

$c$ $c$ $c'$ $c'$ represent inclined tubes located above the fire-boxes, the forward portions of said tubes being separated by spaces, through which the products of combustion from the fire-boxes pass upwardly to the chamber or space $d$ above said tubes. A vertical wall or baffle-plate $e$ extends from the top of the bridge-wall across the series of tubes and to the space or chamber $d$, where said wall terminates, the wall $e$ forming a barrier between the space over the fire-boxes surrounding the front portions of the tubes $c$ and a corresponding, although preferably shorter, space surrounding the rear portions of the tubes and extending from the rear portion of the chamber $d$ downwardly to a space or chamber $d'$ below the rear portions of the tubes and behind the bridge-wall $b$. The front and rear ends of the tubes $c$ $c'$ are inserted in front headers $f$ and rear headers $f'$, the headers $f$ collectively forming a front wall and the headers $f'$ a rear wall. The upper ends of the headers $f$ are connected by tubes $f^2$ with the steam-drum $g$, while the upper ends of the headers $f'$ are connected by tubes $f^3$ with said steam-drum, the tubes $f^2$ entering the drum $g$ at a higher level than the tubes $f^3$, so that the steam and hot water, which are caused by the inclination of the tubes $c$ $c'$ to flow upwardly into the headers $f$, pass from thence into the steam-drum at or above the water-level of the latter, while the water from the lower portion of the steam-drum flows downwardly through the tubes $f^3$ into the headers $f'$ and into the lower ends of the tubes $c$ $c'$.

$h$ represents a water-drum located below and connected with the lower ends of the headers $f'$, said drum being connected by horizontal tubes $i^6$ and vertical tubes $i'$ with the lower portion of the steam-drum $g$.

The products of combustion from the fire-boxes pass upwardly between the forward portion of the tubes $c$ $c'$ into the space or chamber $d$, an inclined baffle-plate $e'$ forming an extension of the wall $e$, causing the products to pass into the forward portion of said chamber $d$, as indicated by arrows in Fig. 2. The products of combustion pass through the chamber $d$, over the baffle-plate $e'$, across the upper end of the wall $e$, and then pass downwardly between the rear portions of the tubes $c'$ and $c$ to the chamber $d'$. The end portions of the space or chamber $d'$ communicate with vertical flues or uptakes $i$ $i$, Fig. 3, which are formed by vertical walls or partitions $j$ $j$, located between the rear portions of the tubes $c$ $c'$ and the end portions $j'$ of the external casing. The said flues $i$ extend from the chamber $d'$ to the ends of a supplemental chamber $m'$, formed by a casing $m$, located above the series of tubes at the rear side of the steam-drum, as shown in Fig. 2. The escape flue or stack $o$ extends from the upper portion of thechamber $m'$, and in said chamber is located a feed-water heater composed of a connected series of

tubes $p$, having suitable connections at one end with a source of water-supply and at the other end with the steam-drum $g$. To afford space for the vertical flues $i\ i$, two headers $f'$ are omitted from the ends of the series of rear headers, and the tubes $c\ c'$ that would have entered the omitted headers $f'$ are connected with vertical tubes $i^{10}$, which are located beside the tubes $i'$ and take the place of the omitted headers $f'$. The series of tubes $c'$ therefore has a wider forward portion in front of the bridge-wall and a narrower rear portion behind the bridge-wall, said narrower portion providing for the flue-spaces $i$ beside the rear portion of the series of tubes, so that said flue-spaces do not involve any elongation of the casing.

It will be seen that the described construction causes the products of combustion after passing upwardly between the forward portions of the tubes $c\ c'$ to pass downwardly between the rear portions of said tubes and then pass through the feed-water heater before escaping, the entire arrangement being such that economy of space and an economical use of the fuel are obtained. This generator is well adapted for use on sea-going vessels of small size, such as steam-yachts, owing to its compact form.

It is obvious that the arrangement may be such that the products of combustion will pass downwardly through the flues $i\ i$ from the chamber $d$ to the chamber $d'$ and then upwardly between the rear portions of the tubes $c\ c'$ to the chamber $m'$ and through the feed-water heater. I do not consider the last-mentioned arrangement, however, so desirable as that first described, it being obviously more advantageous to pass the products of combustion directly from the chamber $d$ downwardly between the rear portions of the tubes $c$ and $c'$ and then upwardly to the feed-water heater.

The vertical tubes $i^{10}$, which take the places of the omitted headers $f'$, serve also to support the steam-drum, and as the tubes $i'$ extend from the lowest portion of the steam-drum and are connected by the tubes $i^6$ with the water-drum a flow of water from the steam-drum to the water-drum is insured so long as any water remains in the steam-drum.

The tubes $i'$ are connected with the steam-drum by means of flanges $i^2$, formed on the tubes $i'$ and bolts $i^3$, passing through said flanges into the steam-drum. To insure a tight joint, a sleeve or nipple $i^4$ is expanded in the orifice formed in the steam-drum to connect it with the tube $i'$, said orifice being smaller than the interior of said tube. The sleeve $i^4$ extends into the tube $i'$ and is expanded against the inner surface of the latter, the tube being preferably provided with an internally-projecting annular seat $i^5$, against which the outer portion of the sleeve $i^4$ is expanded. This connection may be applied to other parts of the apparatus—for example, where the headers $f'$ join the water-drum $h$.

The wall or partition $e$ may be formed by inserting suitably-shaped sections of fire-brick between the tubes $c\ c\ c'\ c'$, or said wall may be hollow and formed as a water-leg, its interior communicating with the said tubes, in which case the wall may be composed of a series of headers, like the headers $f$ or $f'$, and the tubes instead of extending continuously across the bridge-wall would each be made in two parts or sections expanded into the headers forming the wall $e$. The walls or partitions $j\ j$ may also be made by inserting sections of fire-brick between the outer vertical rows of tubes at the rear of the wall $e$.

I claim—

1. A boiler or steam-generator comprising a fire-box, a series of tubes extending lengthwise of the fire-box, a partition located above the bridge-wall and extending crosswise of the tubes, some of the tubes being relatively long and extending rearwardly from the said partition, while other tubes are relatively short and terminate at or near said partition, whereby flue-spaces are formed at the rear of the partition within the length of the longer tubes, said partition causing the products of combustion rising from the fire-box to pass between the tubes at the front of the partition, an elevated space or chamber above the tubes to receive the products of combustion, an escape flue or stack, a lower space or chamber below the tubes at the rear of the partition, and flues or passages located in said spaces, said lower chamber and flues constituting connections between the elevated chamber and the stack, whereby the products of combustion received by the elevated chamber are conducted first downwardly and then upwardly, the said products being presented to the tubes at the rear of the partition in their passage from the elevated chamber to the stack.

2. A boiler or steam-generator comprising a fire-box, a series of tubes extending lengthwise of the fire-box, a partition extending across the series of tubes between their forward and rear portions, the said series being narrower at the rear than at the front of the partition, said partition causing the products of combustion rising directly from the fire-box to pass between the wider forward portion of the series of tubes, an elevated space or chamber above the tubes to receive the products of combustion, an escape flue or stack, a lower space or chamber below the narrower rear portion of the series of tubes, and side flues or passages located beside the narrower portion of the series of tubes and beside the lower chamber, said lower chamber and side flues constituting connections between the elevated chamber and the stack, whereby the products of combustion received by the elevated chamber are conducted first downwardly and then upwardly, the said

products being presented to the rear portions of the tubes in their passage from the elevated chamber to the stack.

3. A boiler or steam-generator comprising a fire-box, a series of tubes extending lengthwise over the fire-box and across the bridge-wall of the fire-box, a partition extending across the series of tubes between their forward and rear portions and extending partly over the forward portions of the tubes, said partition causing the products of combustion rising directly from the fire-box to pass between the forward portions of the tubes including their forward ends, an elevated space or chamber above the tubes to receive the products of combustion from between the forward portions of the tubes, a lower space or chamber below the rear portions of the tubes, an escape flue or stack, and connections between the stack, the lower chamber, and the elevated chamber, whereby the products of combustion received by the elevated chamber are conducted first downwardly and then upwardly, the said products being presented to the rear portions of the tubes in their passage from the elevated chamber to the stack.

4. A boiler or steam-generator comprising a fire-box, a series of tubes extending lengthwise over the fire-box and across the bridge-wall of the fire-box, a partition extending across the series of tubes between their forward and rear portions and extending partly over the forward portions of the tubes, said partition causing the products of combustion rising directly from the fire-box to pass between the forward portions of the tubes including their forward ends, an elevated space or chamber above the tubes to receive the products of combustion from between the forward portions of the tubes, a lower space or chamber below the rear portions of the tubes, an escape flue or stack, connections between the stack, the lower chamber, and the elevated chamber, whereby the products of combustion received by the elevated chamber are conducted first downwardly and then upwardly, the said products being presented to the rear portions of the tubes in their passage from the elevated chamber to the stack, and a feed-water heater arranged to be acted on by the products of combustion rising from the rear portions of the tubes.

5. A boiler or steam-generator comprising a fire-box, a series of tubes extending lengthwise over the fire-box and across the bridge-wall of the fire-box, a partition extending across the series of tubes between their forward and rear portions, said partition causing the products of combustion rising directly from the fire-box to pass between the forward portions of the tubes, an elevated space or chamber above the tubes to receive the products of combustion from between the forward portions of the tubes, a lower space or chamber below the rear portions of the tubes, a supplemental casing or chamber above the rear portions of the tubes, an escape flue or stack connected with the supplemental chamber, flues or uptakes connecting the ends of the lower chamber with the ends of the supplemental chamber, the arrangement being such that the products of combustion pass from the elevated chamber downwardly between the rear portions of the tubes, to the lower chamber, and from thence through the uptakes, to the supplemental chamber, and a feed-water heater in the supplemental chamber.

In witness whereof I have signed my name to this specification in the presence of two subscribing witnesses.

KENNEDY PARK.

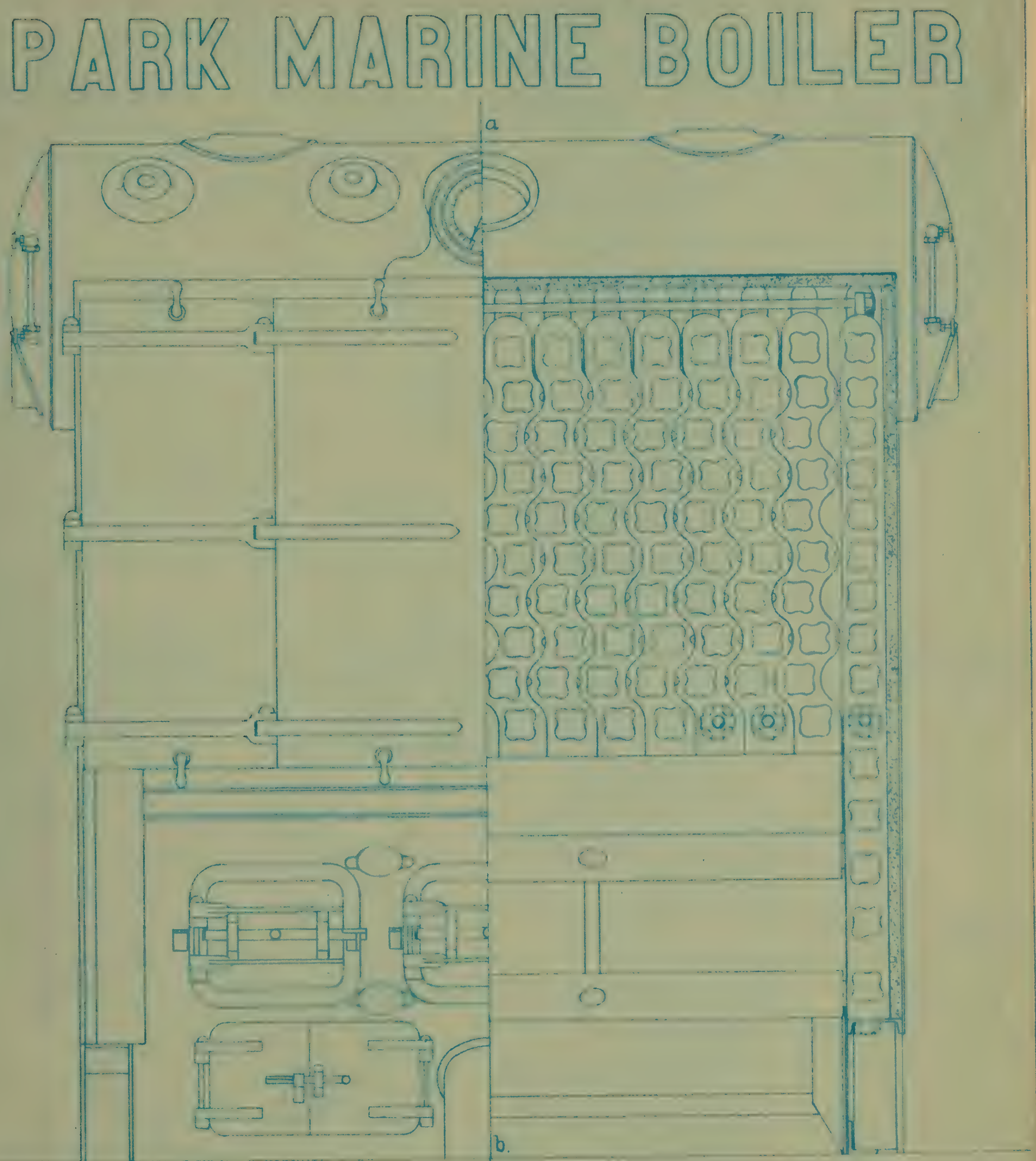
Witnesses:
C. F. BROWN,
A. D. HARRISON.

is known as the "Park Marine Boiler", for which Letters Patent No. 627521 were issued on June 27, 1899 and Reissued Letters Patent No. 11870 dated November 13, 1900. The Specification forming part of the Reissued Letters Patent is bound with this page.

The distinguishing features of the Park boiler are the path of the gases, and the construction necessary to produce such a path. Three drawings are presented; the first (Fig. 1, page 9) is a front view with one half of the front of the casing removed; the second (Fig. 2, page 10) is a longitudinal section through the center; and the third (Fig. 3, page 11) is a

transverse section to the rear of the drum, looking forward.

The steam and water drum is placed transversely and supported upon two headers, one at each end, which are bolted to the drum and to the foundation. Beneath the drum and placed longitudinally are the generating tubes, inclined at an angle of 15° to the horizontal and arranged in groups or sections vertically, the tubes being expanded into front and rear headers, and these headers connected to the drum by means of circulating tubes. The rear headers are connected at the bottom to a mud drum to which they are bolted. Two section fr-

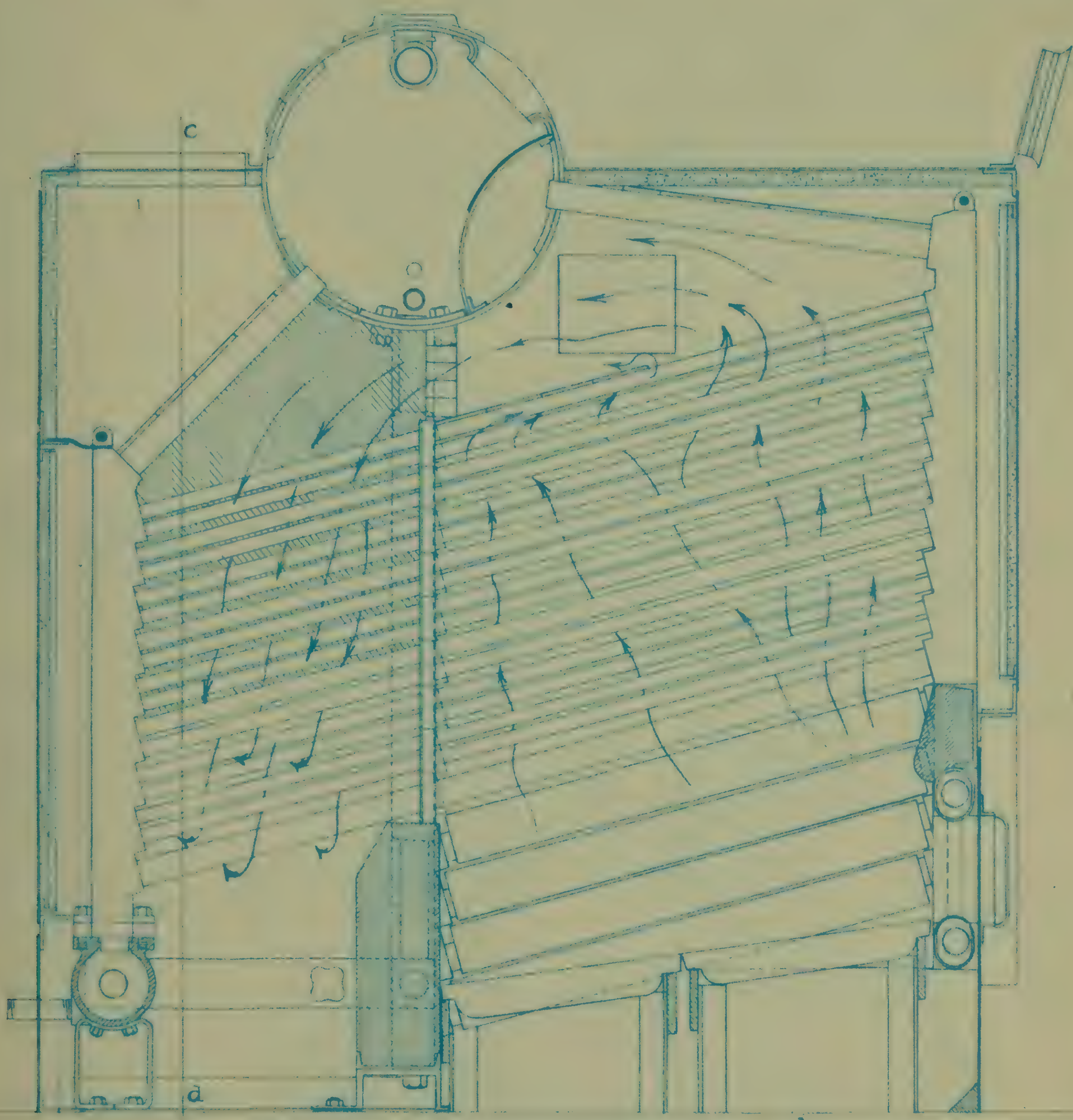


FRONT VIEW.

FIG. I.

N.R.B.

# PARK MARINE BOILER

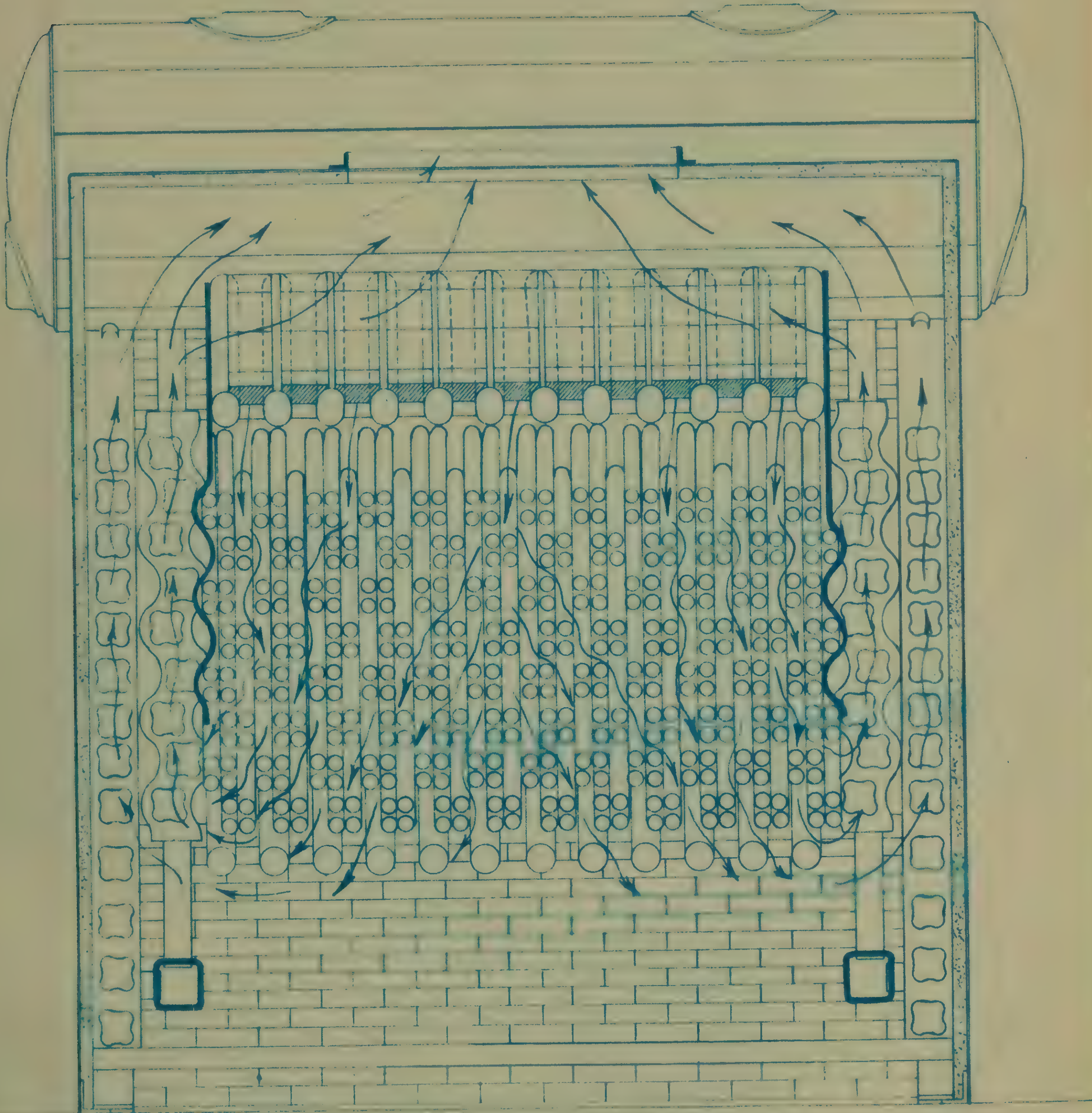



LONGITUDINAL SECTION ON a-b.

FIG. 2.

J.R.B.

# PARK MARINE BOILER



SECTION ON C-d, LOOKING FORWARD.

FIG. 3.

N.R.B.

each side extend only from the front to the steam drum while the others extend to the mud drum. Two transverse boxes connect the outside front headers at points above and below the firing doors. The headers beneath the drum, and therefore the short side sections, are connected to the mud drum by square boxes for the purpose of efficient circulation.
The side headers extend below the other headers for the purpose of receiving the furnace side boxes, which consist of oval tubes.
A fire brick baffle extends across the boiler beneath the drum, the tubes passing through the brick of the baffle (see Fig. 2). Two

vertical baffles of cast iron faced with fire clay extend from the transverse baffle to the rear headers, and are clamped to the outside row of tubes (see Fig. 3). The arrows show the path of the gases (see Figs. 2, 3). The gases rise from the fire upon the grate and pass upward between the tubes in front of the transverse baffle, beneath the drum, over this baffle, down between the tubes, under the longitudinal baffles in the rear and flowing upward in the side passages, behind the short side sections, and over the tile baffle, laid on the rear circulating tubes, pass out through the breeching at the top of the casing.

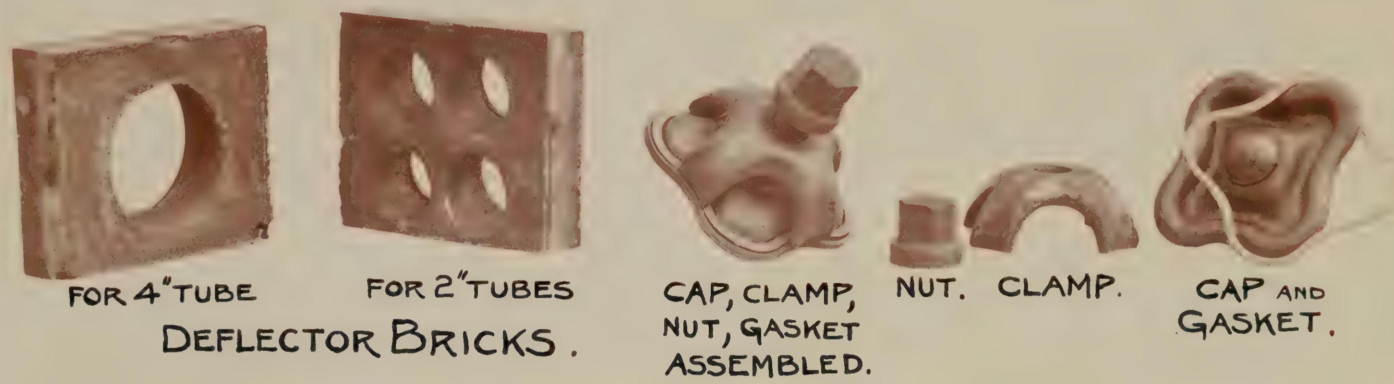
Having thus briefly stated the general principles of the design we will now take up the parts and discuss the details and reasons for their design.

It was decided to use a row of 4 inch diameter tubes over the fire, and above these eight rows of groups of four 2 inch diameter tubes, and above these a row of 4 inch diameter tubes connecting the headers with the steam drum. The reason for placing 4 inch diameter tubes in the first row above the fire is that this row is subject to the most intense heat and evaporates more water per square foot of heating surface than any other row, and the rapid generation of steam bubbles

would drive the water out of a small diameter tube leaving nothing but steam. In the 4 inch diameter tube the body of water present is sufficient to keep water in the tube at all times, and thus decrease the possibility of burning a tube.
In laying out the tubes entering the header it was necessary to stagger the groups of tubes so that no direct path could be taken by the gases; it was necessary to space the tubes so that there was sufficient space for the gases to pass between the tubes of each group; it was necessary that the distance between centers of headers be made a minimum; and it was necessary that the

headers, certain handholes of such shape and so located that any tube, either two inches diameter or four inches diameter, could be removed without removing another tube. Added to this it was necessary to make the headers of sufficient strength, of minimum weight and capable of manufacture at a reasonable cost. Aside from the strength it was necessary to balance the other essentials, as it was impossible to consider one without the other. The header is designed to stand vertical with the generating tubes entering at an angle of 75° (15° to the horizontal) and is a steel casting. A handhole was designed of such a shape

(see Fig 5, page 19 & Fig. 7 page 21) that all four of the 2 inch tubes of a group could pass through it or one 4 inch tube could pass through. The handhole is faced off on the inside forming a 3/8 inch plane face, against which an inside cap makes a joint with a lead gasket. A bolt is riveted to the cap and a clamp and nut on the outside of the header force the cap and gasket against the seat making a steam tight joint (see Fig. 5, page 19). The cap contains a groove into which the gasket is forced thus making the thickness of lead in the joint very small, and overcoming the possibility of the gasket blowing out. The cap and clamp are drop forged and




PARK MARINE BOILER.

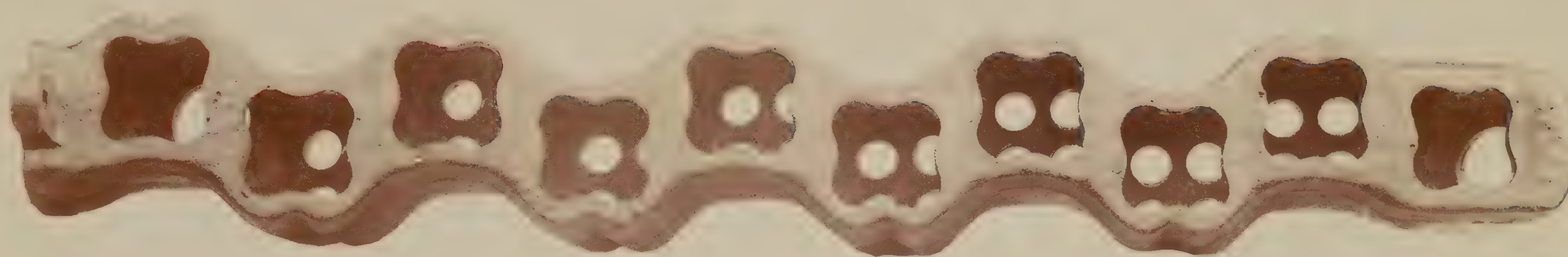
FIG. 4.

"Flowed Steel" Front Header (cap face).
Park Marine Boiler.

Fig. 5.

"Flowed Steel" Front Header (Tube Face).
Park Marine Boiler.

Fig. 6.



"Flowed Steel" Rear Header.
Park Marine Boiler.

Fig. 7.

the nut is malleable iron.
Figure 4 shows the cap, clamp, gasket and nut (page 18). Figures 5, 6 and 7 show views of the headers (pages 19, 20 and 21). Five patterns of headers are used in the boiler. The rear headers (Fig. 7 page 21) have lugs cast at the bottom so that the header can be bolted to the mud drum, and thus relieve the lower nipples of the strain brought on by the pitching of the ship. The side headers supporting the steam drum are bolted to the drum but the steam joint is made by an expanded nipple, which is relieved of any strain by the bolts. The same construction is used where the rear headers rest on the mud drum, - the

bolts taking the strain and the expanded nipple making the steam joint. Figure 2 shows a small separator piece between the rear headers and the mud drum. If a rear header had to be removed it would be necessary to slide it out between the other headers at an angle of 15° to the horizontal, and if the header rested on the mud drum this would be impossible. The separator and nipple must be removed first and then the header can slide out. The front and rear outside headers have lugs at the top through which tie rods pass. These tie rods are used to hold the headers together and prevent the working loose of the expanded

tubes connecting the headers with the drum. The joints between the tubes and the headers are all made by expanding the tube into the header with a roller expander.
This boiler is constructed so that the soot can be blown from the tubes and other heating surface by opening the front and rear doors and not from the sides as in other types of boiler.
The object of blowing the boilers from the front and rear is to enable the placing of the boilers close together. Grooves are made in the sides of the front and rear headers, through which the steam lance can be thrust. The lance is made so that the

steam flows at right angles to the axis of the tube and has proved very efficient in practice. The grooves in the headers are shown in Figures 4, 5, 6 and 7 on pages 7, 19, 20 and 21.

The rear headers are fastened rigidly at the bottom to the mud drum, which is fastened to the ship. The two side headers supporting the steam drum are tied together at the bottom by a steel channel, which is fastened to the ship and also serves the purpose of supporting the bridge wall. The front side headers are fastened at the bottom to the structural foundation, which in turn is secured to the ship.

A steel channel is bolted to the

side front headers, and not only ties them together just above the fire doors but also serves as a support to the other front headers, which are free to move forward, when the tubes expand by heat, but are held in place transversely by the side headers. Two water legs connect the side front headers, one above and one below the fire doors, and assist in the circulation, keep the front cool, and act as front mud drums. The cross channel in front is protected from the heat of the furnace by a special fire brick, and the front plate between the fire doors and above the grate is likewise protected. Round coal boxes in the side sections

form an efficient furnace wall. The side sections containing these furnace boxes are connected with the mud drum by a square circulating box, which also serves the purpose of draining these boxes through the blow-off.

The transverse baffle or flame bridge is made of a specially designed brick which is shown in Figure 4, page 8. This brick is slipped over the tubes when the section is being assembled, and in order to protect it from breaking a thin cover of iron is cast over the rear face and dovetailed into the sides. This brick has proved very durable and practically indestructable and prevents a

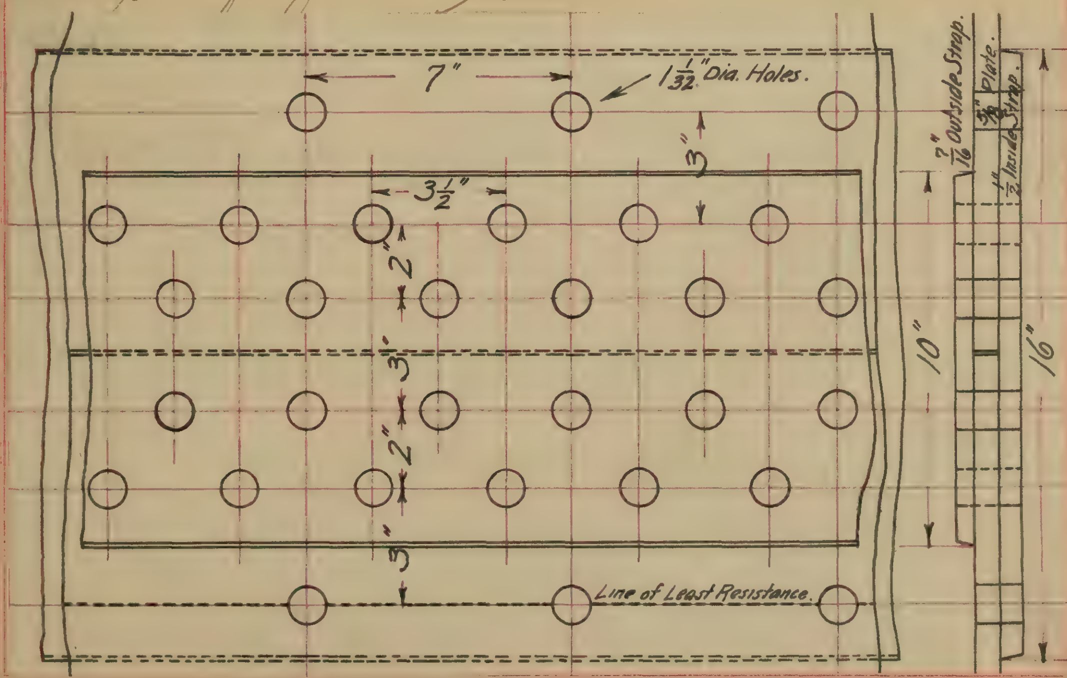
fire brick face to the flame. The joints between the bricks are closed by cast iron flame bars laid across between the tubes and against the back of the baffle. The vertical side deflectors are made of cast iron with projections on the inside face which serve to hold a coating of fire clay. Fire brick tile form the horizontal baffle supported by the tubes in the front and rear of the steam drum. Three tile hang in the space between the tubes and thus form, with the tubes, a baffle for the gases.

The drum used in this experimental boiler is 42 inches in diameter and is designed to carry a working pressure of 270 pounds per square inch.

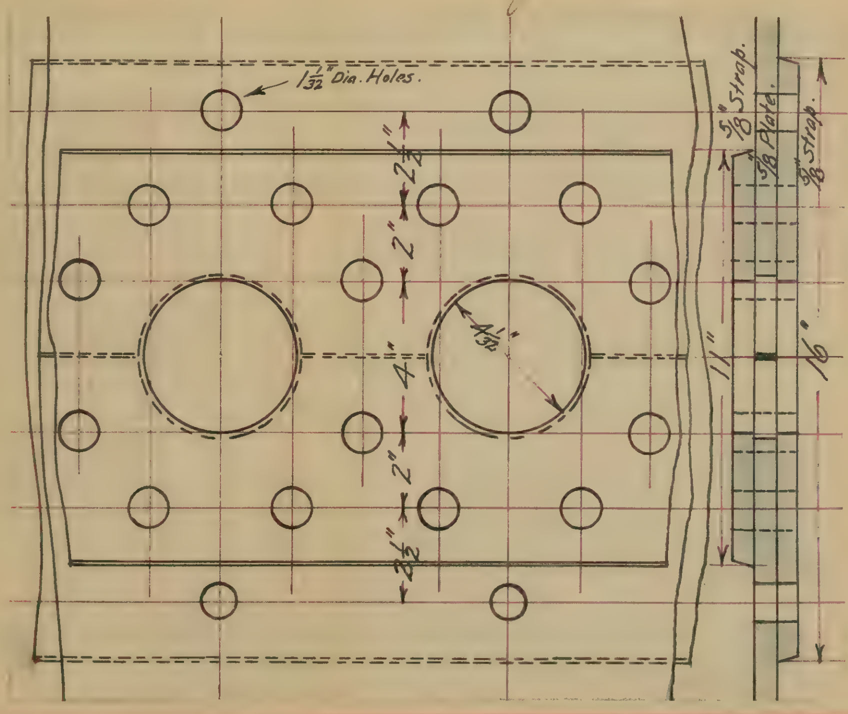
The boiler was designed for sixteen sections of tubes and it was impossible to get a plate of sufficient size to make the drum of one piece. The construction of the boiler made a girth seam impossible because the circulating tubes from the front and rear headers, entered the drum too close together to permit of a lap seam passing between them.

It was therefore necessary to make two longitudinal seams and one was made a triple riveted butt strap joint on the rear side of the drum above the casing, and the other joint was made along the center line of the rear circulating tubes. Plate 5/8 inch thick was used for the shell of the drum;

and tests made on all the plates, heads and straps entering the construction of the drum, gave 61320 pounds per square inch as the minimum tensile strength with an elongation of 28% and reduction of area of 54.7%. With a factor of safety of 5 the safe working pressure for the drum with a 100% joint would be 365 pounds per square inch.
The sketch shows the triple riveted butt strap joint used.



The line of least resistance to bursting is shown by the dotted line (the plate tearing on this line) and the minimum efficiency of this joint is 85.36%." In these calculations tensile strength has been taken as 100, shearing strength 85, and compressive strength 150. The sketch below shows the design of the joint along the centre line of the rear circulating tubes.



In this joint the rivets were necessarily spaced symetrical with the tube holes, and this together with the large holes cut into the plate for the tubes made it necessary to sacrifice efficiency. The lowest efficiency of this joint is 74.9%, and the joint would fail by crushing the two inner rows of rivets and shearing the outer row. After the drum was built, in going over the figures, it was discovered that the efficiency of this joint could be made 81.1% by making the outside strap the same width as the inside strap. In this joint it was necessary to make the two inner rows of rivets 4 inches apart, instead of 3 inches

as in the first joint; because the holes cut in the straps for the tubes would have caused the straps to tear more easily on a line through the tube and rivet holes than along the center line. In order to make up for the metal removed by boring out the 4 3/32 inch diameter holes it was necessary to make both straps of the same thickness as the plate in the shell. The efficiency along the line of the tube holes is 94%. In this joint the tubes have two expanded joints one in each strap. Taking the lowest efficiency of this joint, the drum will be capable of carrying a working pressure of 273 pounds. The heads of the drum were

made $\frac{3}{4}$ inch thick, although theoretically $\frac{5}{8}$ inch would have been heavy enough. They were pressed hot to a radius equal to the diameter of the drum and the increased thickness more than compensates for the drawing of the metal in the flange during pressing.
All the nozzles on the drum are flanged from plate and riveted to the drum. The manhole is flanged, in the shell, by hand over a former, and a reinforcing ring shrunk on, which had been pressed hot from a plate.
"The efficiency of that section of the plate occupied by the manhole is 88.30% which is greater than the efficiency of either longitudinal joint." "Along the line of the

front circulating tubes a 5/8" re-
inforcing strap is riveted to the
inside of the sheet. The tubes
are expanded into the plate
of the drum and the holes in
the reinforcing strap are made
4¼ inches in diameter, in order
to clear the tube which is bulged
slightly in expanding. The
lowest efficiency of the shell
along this strap is 86.+% which
is higher than that of the
longitudinal joints. The efficiency
of the joint made between the
flanged head and the shell of
the drum is 66% which is
ample since it need only be
one half that of the longitudinal
joints. The joints are all
caulked both inside and outside the drum.

The mud drum is made of cast steel of a special grade, the same mixture as that used in the headers, and the thickness of the walls was governed more by the desire to get a perfect casting than to fulfill the results of calculations. Taking 60000 pounds per square inch as the tensile strength of the cast steel, and assuming a factor of safety of 5, the drum would stand a safe working pressure of 1714 pounds per square inch. Ribs were placed between the nipple holes and the efficiency along this line is 70% reducing the safe working pressure to 1200 pounds per square inch. A mistake was made in adding metal to reinforce the

hand holes and the efficiency along this line is only 44% which reduces the safe working pressure to 754 pounds per square inch. This drum is much stronger than necessary and, with the hand holes properly reinforced, the thickness of the metal could be one half what it is now; but a better casting can be made, of this size, 3/4 inch thick than 3/8 inch thick.

The furnace side boxes are pressed from 4 inch extra heavy pipe with the weld away from the fire; and with a factor of safety of 10 (on account of the weld) have a safe working pressure of 946 pounds per square inch. Pipe was used on this boiler

because it could be secured (at that time) more readily, but in all future boilers the furnace side tubes and front cross tubes will be secured from drawn tubing.

The 4 inch diameter tubes are No. 6 (Birmingham) gauge and with a factor of safety of 5 and tensile strength of 50800 pounds per square inch should carry safely 1130 pounds pressure per square inch.

The 2 inch tubes are No. 5 gauge and should have a safe working pressure of 1976 pounds per square inch. These tubes are much heavier than is necessary but present practice demands such heavy tubes. These tubes are of course, cold drawn seamless.

The headers, if without openings for hand holes or tubes, would have a safe working pressure of 2000 pounds per square inch, but the hand holes cut so much of the metal away, that even though a rib is placed between them, the safe working pressure is reduced to 585 pounds per square inch.

In this particular size of boiler each section consists of one 4 inch diameter tube and 32 - 2 inch diameter tubes expanded into front and rear headers, with front and rear 4 inch diameter circulating tubes, connecting the headers to the drum. The size of the boiler is varied either by changing the length of the tubes, the number of tubes in

a section, the number of sections or by any combination of these changes.
In erecting this boiler as each section was built it was tested to 750 pounds per square inch with cold water. The drum was tested to 500 pounds per square inch, and the cast steel pipes, connecting the side sections to the mud drum were tested to 1000 pounds per square inch. The furnace side boxes were tested to 500 pounds pressure per square inch. After the boiler was erected, and before the casing was put on, a cold water test of 500 pounds per square inch was made and the boiler was perfectly tight. It was not necessary

to put the sections as high as 750 pounds or the cast steel tubes to 1000 pounds, but it was done to prove the fallacy of some of the arguments against the use of cast steel for a pressure part. Higher pressures would have been tried had the rings, which were used to close the openings for the circulating tubes, been safe and tight.

The casing is made of structural shapes and sheet steel lined with an asbestos board 1/4 inch thick, next to the sheet, and 1 3/4 inch thick "magnabestos" blocks inside, next to the tubes. All those parts of the casing that do not press against tubes or headers, and are therefore acted upon directly by the gases have

a thin metal sheet to protect the magnabestos from the cutting action of the gases. After a 24 hour run, in which the average evaporation per square foot of heating surface was 4.6 pounds of water, the palm of the hand could be placed on any part of the casing without pain, thus proving the insulating efficiency of the casing.

Figure 8 page 43 is a view of the boiler during the course of erection, and after the previous description of the parts the picture will be self explanatory.

At this point let us see how well the "Park Marine" boiler fulfills the seven requirements mentioned at the beginning of this paper.

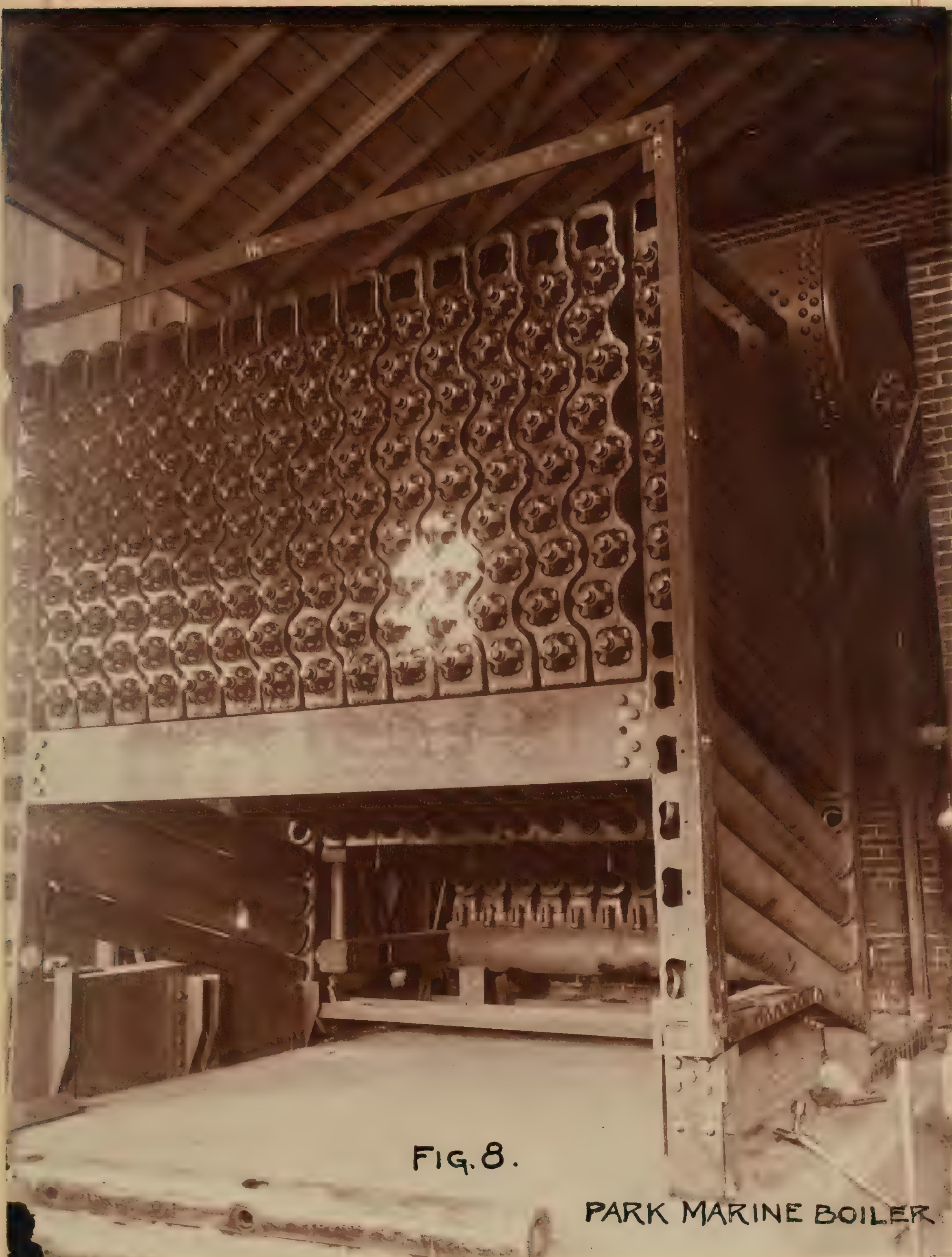


FIG. 8.

PARK MARINE BOILER

(1) Limited Space:— The experimental boiler occupies 121.5 square feet of floor space and has a cubical content of 1424.5 cubic feet. It has 2709 square feet of heating surface and therefore 1.9 square feet of heating surface per cubic foot of volume. Referring to the table of comparative figures of marine boilers the relative value of this number is readily seen.

# COMPARISON OF MARINE BOILERS.—

| NAME OF BOILER. | HEATING SURFACE | GRATE SURFACE | RATIO H.S. G.S. | FLOOR SPACE. SQ. FT. | WEIGHT BOILER EMPTY. | WEIGHT OF WATER. | WEIGHT. SQ. FT. H.S. EMPTY. | WEIGHT SQ. FT. H.S. WITH WATER | VOLUME CU. FT. | RATIO H.S VOLUME. | STEAM SPACE CU. FT. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCOTCH 210 POUND. | 2850 | 68.0 | 41.8 | 160.1 | 122877 | 48450 | 43.1 | 60.1 | 1601.2 | 1.77 | 303.6 |
| B. AND W. | 2640 | 63.2 | 41.7 | 117.9 | 53304 | 9498 | 20.2 | 23.8 | 1442.7 | 1.82 | 45.5 |
| NICLAUSSE | 2222 | 56.7 | 38.6 | 127.1 | 69390 | 14316 | 25.7 | 31.0 | 1239.2 | 1.78 | 33.2 |
| BELLEVILLE | 1336 | 41.6 | 32.1 | | 38560 | 3733 | 28.8 | 31.6 | | | |
| THORNYCROFT | 3095 | 63.0 | 49.1 | 124.8 | 35078 | 4980 | 11.5 | 13.5 | 1279.9 | 2.42 | 42.3 |
| YARROW | 2000 | 50.0 | 40.0 | 119.2 | 19560 | 6200 | 9.8 | 12.8 | 1217.5 | 1.64 | 44.3 |
| ALMY | 1020 | 29.5 | 34.7 | 43.2 | 11700 | 1500 | 11.5 | 12.9 | 302.7 | 3.36 | |
| PARK | 2709 | 54.0 | 50.0 | 127.7 | 61582 | 10830 | 22.7 | 26.7 | 1424.5 | 1.90 | 55.7 |

J. C. COOK. J. ROWLAND BROWN

(2) Minimum Weight:— The weight of this boiler empty is 6,582 pounds, and when steaming at 200 pounds pressure, with the water level at the center of the drum, the total weight is 7,2412 pounds. The weight empty per square foot of heating surface is 22.7 pounds and the weight including water per square foot of heating surface is 26.7 pounds. By reference to the table the relative values of these figures can be determined.

(3) Safety:— From the calculations, the results of which have been given above, and from the results of the cold water tests, it is evident that the boiler is designed to withstand a pressure in excess of that which is its rated safe

working pressure, and that the materials of its parts are free from defects and its workmanship safe. Three classes of material, largely, go to make the pressure parts; - rolled steel plate, cold drawn tubing and cast steel. Of these the first two are conceded to be the best selection possible. Of the latter, opinions differ. A word as to the superiority of cast steel in the construction of a header or manifold: - Boiler builders have discarded the welded tube because it is welded, - and everyone knows that a weld is a dangerous makeshift - yet these same builders cry out loudly against the use of cast steel for pressure parts and proclaim

the superiority of wrought steel with a welded joint. Cast steel pressure parts properly made, inspected and tested, combine the rigidity (resistance to change of shape) of cast iron with the toughness of wrought steel and possess a strength greater than either. From the description and drawings it is readily seen that this boiler is sectional and has the pressure parts so sub-divided that a disastrous explosion is impossible.

(4) Repairs:— Instances are on record of boilers being operated for years under severe conditions without undergoing repairs, but such boilers are exceptional. Even in the best acknowledged types of boilers repairs are

expected and provision made for making such; in fact, a boiler is not considered good unless it has been designed with special attention to the ease of making repairs. Every part of the "Park" boiler is accessible for repairs and in no case is it necessary to damage another part. Handholes with inside caps are provided in sufficient numbers and so located that any tube or nipple can be removed if necessary. The furnace side boxes and the front cross boxes can be removed, the mud drum and all the headers. The rear longitudinal baffles can be readily removed; and the casing is made sectional so that any part of it can be removed without destroying it

or disturbing any other part. Every tube and nipple in the boiler is straight and of but two sizes, both standard. The headers are not subject to the direct action of the flame and would rarely ever be so ruptured that a repair would be impossible.

(5) Cleaning:— As has been explained before there are grooves made in the sides of the headers to permit the insertion of a steam lance between the headers, for the purpose of blowing the soot and ashes from the tubes. In this way every part of the heating surface can be readily cleaned. Doors are placed in the casing, front and rear, giving access to all the headers and the rear side uptakes. Access

can be had to all tubes and boxes by the removal of the inside caps from the headers, and to the mud drum through handholes and to the steam drum through a man-hole. A surface blow is provided in the steam drum, and blow-off pipes drain the boiler through the mud drum.
The boiler can be easily washed out and easily drained.
(6) Circulation:- In the "Park" boiler the tubes are inclined at an angle of 15° to the horizontal to insure a continuous circulation in one direction, from the cooler to the hottest parts of the boiler. The course of the circulation is forward through the tubes to the front header, through the front circulating tubes

to the steam drum, down the rear circulating tubes, to the rear headers and again forward through the tubes. A sheet steel baffle is placed in the steam drum opposite the front circulating tubes (see Fig. 2 page 10) to baffle the steam and water entering the drum from these tubes, and prevent the water from being carried away with the steam. Glass bull's eyes in the drum heads show that the circulation is very rapid and that the steam and water from the front tubes is injected into the drum with considerable force, making the baffle necessary. The front cross boxes and the mud drum appear to have little or no circulation, as they collect most of the

mud and other deposits. The front cross box below the fire doors collects the greatest part of the deposit, even more than the mud drum in the rear.

(7) Efficiency:— The efficiency of a boiler should be divided into the efficiency of the combustion chamber and the efficiency of the heating surface. The most efficient combustion chamber is that known as the "Dutch oven" or "dog house" type consisting of a fire brick arch and walls extending in front of the boiler proper and enclosing the grate. Such a construction is of course not permissable in a Marine boiler, as fire brick must be reduced to a minimum and an arch of large size would

not be allowed. A sacrifice in efficiency must then be made in the combustion chamber. The distance from the grate to the lower row of tubes need not be great if anthracite coal is to be burned, but with bituminous coal this distance should be made as great as practicable. Placing fire brick on the lower row of tubes does not take the place of a brick arch, for the lower tubes are still exposed to the unconsumed gases, and if the unconsumed gases are once chilled they will pass away as smoke. The question of height of boiler is an important one in marine work, and as the boiler must come under a

certain height limit it is necessary to further decrease the efficiency of the combustion chamber by making it low. In this boiler a mean was taken which has proved very satisfactory for both anthracite and bituminous coals.

Heating surface absorbs heat from the gases most efficiently when the path of flow of the gases is perpendicular to that heating surface, and in this boiler this principle is carried out most effectively. Most types of marine boilers have but one passage of the gases across the tubes and the escaping gases are necessarily high; but in this type of boiler the gases make two passages across the tubes and therefore

produce the same result as a boiler of almost twice the height. Due to the double passage of the gases the absorption of the heat is more complete and the loss due to escaping gases reduced.

The experimental "Park Marine" boiler has the following general proportions:— 2709 square feet of heating surface, which includes outside tube surface, one half of the surface of the furnace side boxes and that portion of the drum exposed to the gases. The grate is 6 feet deep and has an area of 54 square feet, making the ratio of heating surface to grate surface 50 to 1. This ratio, by comparison with the table on page 44, appears high

but has proved very satisfactory in practice. The steam space when the water is carried at the center of the drum is 55.7 cubic feet, which is, by comparison, (see table page 44) very favorable for a water tube boiler.

At first some difficulty was found, in using cold feed water, to keep the water level steady, but this was overcome by placing a feed distributing pipe, containing perforations, along the bottom of the drum. Now the water level shows no fluctuations when carried below the entrance of the front circulating tubes and only a slight fluctuation when the level is raised. This is due to the force of the rapid circulation through the circulating

tures into the drum.
Figure 9 page 58 is a plan of the experimental boiler and testing apparatus in its test house.
The feed water was measured in calibrated steel tanks which are shown in the corner of the building. The suction pipe to the pumps and injector enters the larger steel tank which stands on the floor. The calibrated tank rests upon the large suction tank and is divided into two compartments by a sheet steel partition. Each compartment has a 4 inch quick opening gate valve which empties the calibrated tank into the large suction tank below. The partition has a notch cut in it at the top, 6 inch deep

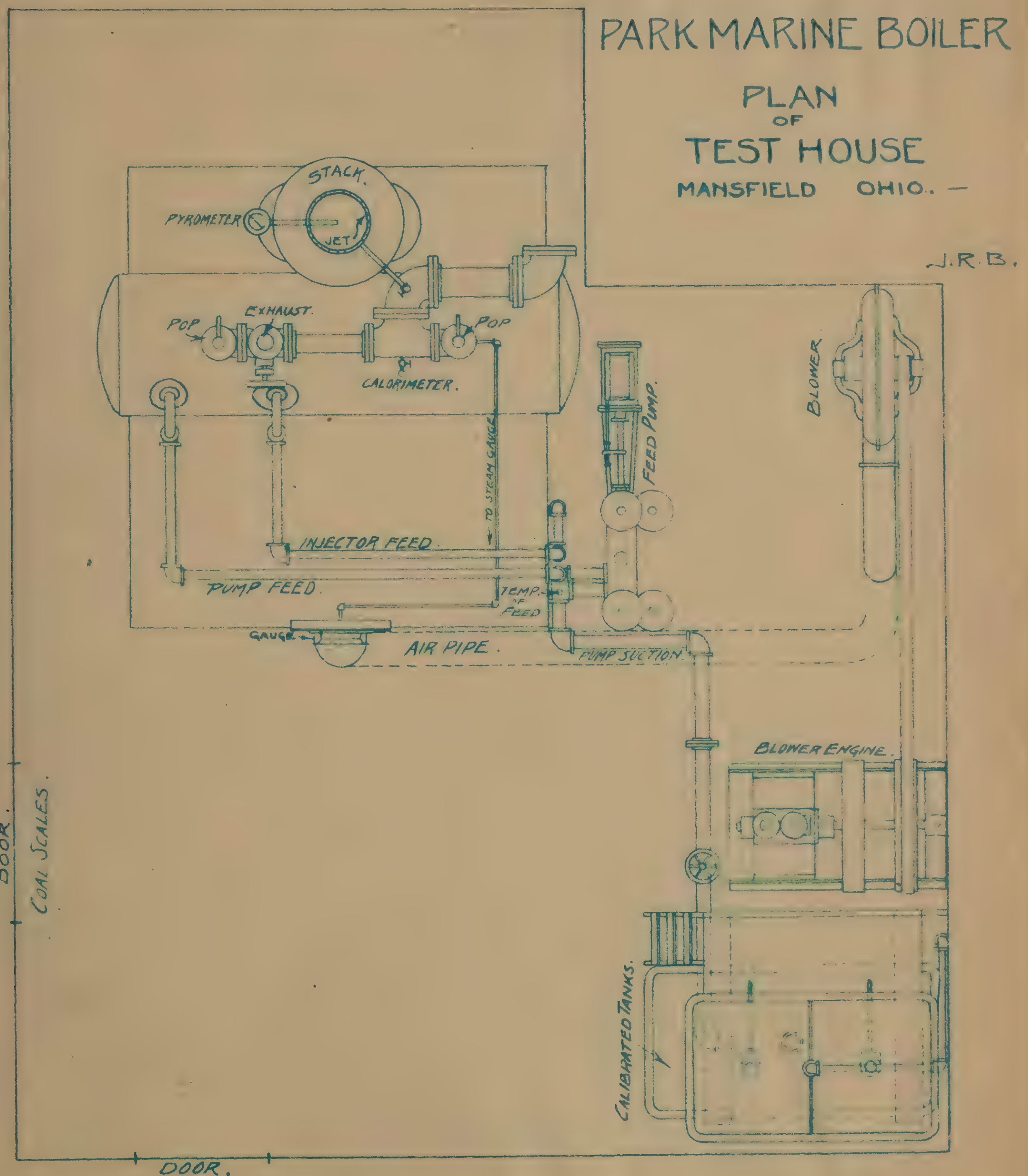

PARK MARINE BOILER
PLAN
OF
TEST HOUSE
MANSFIELD OHIO. —
J.R.B.
STACK.
PYROMETER
JET
EXHAUST.
POP
POP
CALORIMETER.
TO STEAM GAUGE
INJECTOR FEED.
PUMP FEED.
TEMP. OF FEED
GAUGE
AIR PIPE.
PUMP SUCTION.
FEED PUMP.
BLOWER
BLOWER ENGINE.
CALIBRATED TANKS.
DOOR.
COAL SCALES.
DOOR.

FIG. 9.

and 6 inches wide. On each side of the partition is placed a hook gauge with the points of the hooks on a level with the bottom of the notch. On the large suction tank a hook gauge is also used for measuring the level of the water. In starting a test the height of the water in the drum is measured on the glass and the level of the water in the suction tank brought to the point of the hook gauge; and at the end of the test the water levels in the drum and tank are brought to the same points. The water supply has a quick opening valve and a flexible outlet that can be changed

to discharge on either side of the partition. As shown in the plan a platform above the suction tank places the water tender in a position to operate all three valves. The 4 inch quick opening valves in the calibrated tanks are connected to levers, that extend up through the platform within easy reach of the operator. The notch is generally used in tanks of this construction to determine the level by permitting the water to overflow, but this permits a variation of one quarter of an inch. With the hook gauge the levels should never vary by over 1/32 of an inch, which

gives an error of less than 1/10 of 1%; and ordinarily the levels will be within 1/64 of an inch of the correct point. These results are more accurate than can be obtained with scales. Tank No. 1 contains 1985 pounds of water and No. 2 contains 1950 pounds at a temperature of 46°. Both tanks were calibrated by siphoning the water into a barrel placed on scales and weighing, and observing the temperature. Tank No. 1 was recalibrated some time after the first calibration and exactly the same weight was secured. A coil of pipe placed in the bottom of the suction tank heats the feed water, and its tempera-

ture is measured at the point in the suction pipe shown in the plan. A blower and engine were erected as shown. Both the blower and engine had been scrapped but were overhauled and pressed into service with the expectation that they would serve for a few tests; but they did not have capacity enough, as is shown by the low pressure secured on the two tests where they were used. On the second test the engine broke down twice which accounts for the falling off in evaporation over that of previous tests, with the same coal. The position of the Carpenter Throttling calorimeter is shown in the plan. The

sampling pipe of the calorimeter
is a ½ inch pipe perforated
with ⅛ inch diameter holes,
and extends three quarters of
the way across the steam pipe.
The pipe marked exhaust is a
5 inch pipe containing a gate valve
and is used for the escape of
the steam when the boiler is
operated at a pressure too high
to be used in the engines, or
in battery with the other boilers
of the power plant. The pyrometer
was placed in the base of the
stack as shown, and draft gauges
were connected through piping
to the base of the stack and
the ash pit. The scales for
weighing the coal were placed
just inside the door through

which the coal was obtained.

The object in view in making the tests upon this boiler was not to secure a series of trials to use for advertising purposes and show the boiler only at its best; but rather to make a series of tests under ordinary conditions, with average firemen, to determine for the builders the actual value of the boiler and to show any defects that might exist, before the boiler is placed on the market. With this object in view, of securing information rather than spectacular results, the following tests were made. In an investigation of this kind, to throw out all results except those that are good and then draw conclusions from the good

results alone would not be scientific, and in this series of tests the failures are given along with the successes, and more has been learned by assigning the causes for the failures than can be observed by a study of the successes.

Before making the tests all instruments were calibrated or examined carefully. The scales for weighing the coal were correct. The steam gauge was tested by comparison with a standard test gauge which had been calibrated by the makers for such use. Two pyrometers were used, – one being new and the other tested by the maker just previous to the tests. All the chemical thermometers were purchased new from a

| NUMBER OF TRIAL. | DATE. | STATE OF WEATHER. | DURATION. HOURS. | KIND OF FUEL. | METHOD OF FIRING. | REMARKS. | AVERAGE PRESSURES. BAROMETER INCHES OF MERCURY. | BAROMETER POUNDS PER SQ. IN. | STEAM GAUGE. LBS. | ASH PIT INCHES OF WATER. | DRAFT IN STACK INS. OF WATER. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | MAR. 21, '03. | CLOUDY. | 8 | R. OF M. DINGESS W. VA. | LOCOMOTIVE FIREMAN. | 5/8" BARS. | 29.68 | 14.54 | 198.2 | | 1.23 |
| 2. | " 24 | CLEAR. | 8 | " " " " " | SALT WATER " | " " | 29.68 | 14.54 | 197.5 | | 1.09 |
| 3. | " 26 | CLEAR. | 8 | " " " " " | LAKE " | " " | 29.84 | 14.62 | 197.8 | | 1.11 |
| 4. | " 28 | CHANGEABLE. | 8 | " " " " " | " " | " " | 29.80 | 14.60 | 195.8 | | .52 |
| 5. | " 31 | CLEAR. | 8 | " " " " " | SALT WATER " | " " | 29.55 | 14.48 | 196.2 | | .66 |
| 6. | APR. 3 | RAIN. | 8 | ANTHRACITE, EGG. | " " " | " " | 29.17 | 14.29 | 198.2 | | .52 |
| 7. | " 6 | CLEAR. | 8 | " " | " " " | 1/2" " | 29.62 | 14.51 | 199.1 | | .54 |
| 8. | " 7, 8 | CHANGEABLE. | 24 | " " | LAKE & SALT WATER " | " " | 29.54 | 14.47 | 197.1 | | .95 |
| 9. | " 11 | CLEAR. | 2 | " " | SALT WATER " | " " | 29.58 | 14.49 | 196.8 | .52 | .52 |
| 10. | " 14 | RAIN. | 8 | R. OF M. TUG RIVER W. VA. | LAKE " | 3/8" " | 29.08 | 14.25 | 199.2 | | .67 |
| 11. | " 15 | RAIN. | 8 | " " " " " " | " " | " " | 29.25 | 14.33 | 196.4 | | 1.30 |
| 12. | " 16 | CLOUDY. | 8 | " " " " " " | " " | " " | 29.42 | 14.42 | 202.1 | .26 | .34 |
| 13. | " 24 | CHANGEABLE. | 8 | POCAHONTAS LUMP. | LOCOMOTIVE " | 1/2" " | 29.70 | 14.55 | 201.7 | | .60 |
| 14. | " 25 | CLOUDY. | 6 | R. OF M. TUG RIVER W. VA. | " " | " " | 29.60 | 14.50 | 201.9 | | 1.71 |

| Number of Trial. | Average Temperatures. | | | | | Fuel. | | | | | | | | Fuel per Hour. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | External Air. | Fire Room Air. | Feed Water. | Escaping Gases. | Steam from Tables. | Coal as Fired. Lbs. | Weight of Moisture in Coal. Lbs. | Per Cent of Moisture in Coal. | Dry Coal. Lbs. | Ashes and Refuse Lbs. | Per Cent of Ashes in Dry Coal. | Combustible. Lbs. | Coal as Fired. Lbs. | Dry Coal. Lbs. | Combustible. Lbs. |
| 1 | 39 | 57 | 144.6 | 553 | 387.0 | 15668 | 971 | 6.2 | 14697 | 1580 | 10.7 | 13117 | 1958 | 1837 | 1639 |
| 2 | 40 | 55 | 144.0 | 590 | 386.7 | 14550 | 640 | 4.4 | 13910 | 1564 | 11.2 | 12346 | 1819 | 1739 | 1543 |
| 3 | 51 | 63 | 145.0 | 577 | 386.8 | 14175 | 765 | 5.4 | 13410 | 1766 | 13.1 | 11644 | 1772 | 1676 | 1455 |
| 4 | 39 | 62 | 154.9 | 515 | 386.0 | 11057 | 420 | 3.8 | 10637 | 1259 | 11.8 | 9378 | 1382 | 1329 | 1172 |
| 5 | 55 | 68 | 165.2 | 487 | 386.1 | 9735 | 419 | 4.3 | 9316 | 1130 | 12.1 | 8186 | 1217 | 1164 | 1022 |
| 6 | 39 | 53 | 154.8 | 425 | 386.9 | 8436 | 256 | 3.03 | 8180 | 1348 | 16.5 | 6832 | 1054 | 1022 | 854 |
| 7 | 59 | 67 | 141.0 | 516 | 387.3 | 9126 | 359 | 3.93 | 8767 | 1111 | 12.7 | 7656 | 1141 | 1096 | 957 |
| 8 | 53 | 67 | 131.5 | 582 | 386.5 | 33866 | 1263 | 3.73 | 32603 | 4967 | 15.2 | 27636 | 1411 | 1358 | 1151 |
| 9 | 60 | 72 | 133.7 | 681 | 386.4 | 3626 | 128 | 3.53 | 3498 | 518 | 14.8 | 2980 | 1813 | 1749 | 1490 |
| 10 | 49 | 60 | 156.9 | 518 | 387.2 | 11341 | 771 | 6.8 | 10570 | 856 | 8.1 | 9714 | 1417 | 1321 | 1214 |
| 11 | 43 | 58 | 134.8 | 575 | 386.1 | 14529 | 901 | 6.2 | 13528 | 1096 | 8.1 | 12432 | 1816 | 1691 | 1554 |
| 12 | 45 | 63 | 138.0 | 585 | 388.5 | 13340 | 867 | 6.5 | 12473 | 1043 | 8.3 | 11430 | 1667 | 1559 | 1429 |
| 13 | 48 | 60 | 142.7 | 614 | 388.3 | 10078 | 384 | 3.81 | 9694 | 870 | 9.0 | 8824 | 1260 | 1212 | 1103 |
| 14 | 50 | 65 | 112.2 | 602 | 388.5 | 12790 | 572 | 4.47 | 12218 | 1172 | 9.7 | 11046 | 2131 | 2036 | 1841 |

| Number of Trial. | Fuel per Hour. Per Sq. Ft. Grate. As Fired. Lbs. | Dry Coal. Lbs. | Combustible. Lbs. | Calorific Value of Fuel. Per Pound Dry Coal. B.T.U. | Per Pound Combustible. B.T.U. | Coal Analysis. Carbon. | Hydrogen. | Oxygen. | Nitrogen. | Sulphur. | Ash. | Flue Gas Analysis. Carbon Dioxide. | Oxygen. | Carbon Monoxide. | Nitrogen. | Quality of Steam. Moisture. | Factor of Correction. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 36.2 | 34.0 | 30.3 | 13428 | 14502 | 74.12 | 5.09 | 10.98 | | 1.20 | 7.4 | | | | | .006 | .995 |
| 2 | 33.7 | 32.2 | 28.6 | 13428 | 14502 | " | " | " | | " | " | | | | | .006 | .995 |
| 3 | 32.8 | 31.0 | 27.0 | 13428 | 14502 | " | " | " | | " | " | | | | | .004 | .997 |
| 4 | 25.6 | 24.6 | 21.7 | 13428 | 14502 | " | " | " | | " | " | | | | | .003 | .9976 |
| 5 | 22.5 | 21.5 | 19.0 | 13428 | 14502 | " | " | " | | " | " | | | | | .003 | .998 |
| 6 | 19.5 | 18.9 | 15.8 | 13369 | 14296 | 81.84 | 2.76 | 5.62 | .60 | .76 | 6.49 | | | | | .0025 | .998 |
| 7 | 21.1 | 20.3 | 17.7 | 13369 | 14296 | " | " | " | " | " | " | 11.9 | 2.7 | 2.1 | 83.3 | .002 | .9984 |
| 8 | 26.1 | 25.0 | 21.3 | 13369 | 14296 | " | " | " | " | " | " | 10.9 | 1.6 | 1.9 | 85.6 | .002 | .9984 |
| 9 | 33.5 | 32.4 | 27.6 | 13369 | 14296 | " | " | " | " | " | " | | | | | .002 | .9984 |
| 10 | 26.2 | 24.4 | 22.5 | 13873 | 15090 | 78.14 | 4.52 | 7.02 | | 1.68 | 8.07 | 10.7 | 1.7 | 1.7 | 85.8 | .001 | .9992 |
| 11 | 33.6 | 31.3 | 28.8 | 13873 | 15090 | " | " | " | | " | " | 11.2 | 2.0 | 2.3 | 84.4 | .003 | .9977 |
| 12 | 30.9 | 28.8 | 26.4 | 13873 | 15090 | " | " | " | | " | " | 13.1 | 1.2 | 1.5 | 84.2 | .002 | .9984 |
| 13 | 23.3 | 22.4 | 20.4 | 14590 | 15328 | 83.54 | 4.34 | 6.38 | | .40 | 4.82 | 12.3 | 2.4 | 1.1 | 84.3 | .002 | .9984 |
| 14 | 39.5 | 37.9 | 34.1 | 13873 | 15090 | 78.14 | 4.52 | 7.02 | | 1.68 | 8.07 | 11.9 | 3.3 | 0.6 | 84.2 | .004 | .9969 |

| Number of Trial. | Water. Total Feed. LBS. | Water. Equivalent Dry Steam. LBS. | Water. Factor of Evaporation. | Water. Equivalent from and at 212°. LBS. | Water per Hour. Feed. LBS. | Water per Hour. Dry Steam. LBS. | Water per Hour. From and at 212°. LBS. | Water per Hour. From and at 212° per Sq. Ft. Grate. LBS. | Water per Hour. From and at 212° per Sq. Ft. Heating Surface. LBS. | Economic Results. Water per Lb. of Coal (Actual). LBS. | Economic Results. From and at 212° per Lb. of Coal as Fired. LBS. | Economic Results. From and at 212° per Lb. of Dry Coal. LBS. | Economic Results. From and at 212° per Lb. of Combustible. LBS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 105971 | 105441 | 1.126 | 118726 | 13246 | 13180 | 14841 | 274.8 | 5.[illegible] | 6.76 | 7.58 | 8.08 | 9.05 |
| 2 | 101781 | 101272 | 1.126 | 114032 | 12722 | 12659 | 14254 | 264.0 | [illegible] | 7.00 | 7.84 | 8.20 | 9.23 |
| 3 | 87259 | 86997 | 1.125 | 97872 | 10907 | 10875 | 12234 | 226.5 | 4.51 | 6.15 | 6.90 | 7.30 | 8.40 |
| 4 | 71478 | 71306 | 1.114 | 79435 | 8935 | 8913 | 9927 | 183.8 | 3.66 | 6.46 | 7.18 | 7.47 | 8.47 |
| 5 | 61416 | 61293 | 1.104 | 67667 | 7677 | 7662 | 8458 | 156.6 | 3.12 | 6.31 | 6.95 | 7.26 | 8.2[illegible] |
| 6 | 67557 | 67422 | 1.115 | 75176 | 8445 | 8428 | 9397 | 174.0 | 3.47 | 8.00 | 8.91 | 9.19 | 11.00 |
| 7 | 73790 | 73672 | 1.130 | 83249 | 9224 | 9209 | 10406 | 192.7 | 3.8[illegible] | 8.08 | 9.12 | 9.49 | 10.5[illegible] |
| 8 | 265216 | 264792 | 1.139 | 301598 | 11050 | 11033 | 12566 | 232.7 | 4.64 | 7.83 | 8.90 | 9.25 | 10.41 |
| 9 | 28358 | 28313 | 1.137 | 32192 | 14178 | 14156 | 16096 | 298.0 | 5.9[illegible] | 7.82 | 8.87 | 9.20 | 10.5[illegible] |
| 10 | 98104 | 98026 | 1.113 | 109103 | 12263 | 12253 | 13638 | 252.4 | 5.03 | 8.65 | 9.62 | 10.32 | 11.23 |
| 11 | 120847 | 120569 | 1.135 | 136846 | 15106 | 15071 | 17106 | 316.8 | 6.31 | 8.32 | 9.42 | 10.11 | 11.00 |
| 12 | 103148 | 102983 | 1.133 | 116680 | 12893 | 12873 | 14585 | 270.1 | 5.3[illegible] | 7.73 | 8.75 | 9.35 | [illegible] |
| 13 | 80913 | 80783 | 1.126 | 90961 | 10114 | 10098 | 11370 | 210.5 | 4.19 | 8.03 | 9.03 | 9.38 | [illegible] |
| 14 | 98725 | 98419 | 1.159 | 114068 | 16454 | 16403 | 19011 | 352.1 | 7.02 | 7.71 | 8.92 | 9.33 | [illegible] |

| Number of Trial. | Efficiency. | | Heat Balance. | | | | | |
|---|---|---|---|---|---|---|---|---|
| | of Boiler. % | Boiler & Grate. % | Absorbed by Boiler. Per Cent. | Loss due to Moisture in Coal. | Loss due to Burning Hydrogen. | Loss in Escaping Gases. | Loss due to Incomplete Combustion of Carbon. | Losses due to Radiation etc. |
| 1 | 60.2 | 58.1 | 60.2 | | | | | |
| 2 | 61.5 | 59.0 | 61.5 | | | | | |
| 3 | 55.9 | 52.5 | 55.9 | | | | | |
| 4 | 56.3 | 53.7 | 56.3 | | | | | |
| 5 | 55.0 | 52.2 | 55.0 | | | | | |
| 6 | 74.3 | 66.4 | 74.3 | | | | | |
| 7 | 73.4 | 68.5 | 73.4 | .37 | 2.33 | 11.7 | 9.31 | 2.89 |
| 8 | 73.7 | 66.8 | 73.7 | .36 | 2.39 | 14.6 | 9.21 | − .26 |
| 9 | 72.9 | 66.4 | 72.9 | | | | | |
| 10 | 71.8 | 71.8 | 71.8 | .62 | 3.11 | 8.27 | 7.83 | 8.37 |
| 11 | 70.4 | 70.4 | 70.4 | .57 | 3.78 | 12.84 | 9.74 | 2.67 |
| 12 | 65.3 | 65.1 | 65.3 | .60 | 3.85 | 12.10 | 6.35 | 11.80 |
| 13 | 64.9 | 62.0 | 64.9 | .34 | 3.46 | 14.2 | 4.76 | 12.34 |
| 14 | 66.5 | 65.0 | 66.5 | .41 | 3.80 | 14.4 | 2.74 | 12.15 |

reputable maker, especially for these tests. The barometer was an aneroid which had recently been tested at a Government station. The solutions for use in the Orsat gas apparatus were prepared according to proportions given by Professor Carpenter. Samples of the coal were carefully selected, being as near an average as was possible, dried for six hours on top of the boiler, crushed, and sent in sealed jars to the Pittsburgh Testing Laboratory; where an ultimate analysis was made, and the B.T.U. per pound of dry coal determined by an oxygen calorimeter. The per cent of moisture in the coal

was found by the following method-
Each(?) day a sample of the coal
as fired was collected, and dried
on top of the boiler for six hours, under
as nearly similar conditions to those
under which the sample for
analysis was dried, as possible. The
per cent of moisture thus found
was added to that obtained by the
chemist from the sample he received,
and the sum taken as the
total moisture in the coal.
There were no means for determining
accurately the total moisture in
the coal and therefore this method
was resorted to. The scales used
to determine the moisture weigh
to 1/16 of an ounce and samples of
25 pounds were selected thus making
the probable error very small.

In the heat balance all calculations were based on the total heat value of one pound of combustible. The heat absorbed by the boiler was taken as the evaporation from and at 212° per pound of combustible multiplied by 965.8. The loss due to moisture in the coal was found by multiplying the weight of moisture per pound of combustible by the heat required to raise it from water, at the temperature of the fire room, to superheated steam at the temperature of the escaping gases. The loss due to the burning of hydrogen in the coal was determined by multiplying the weight of hydrogen per pound of combustible by 9 and this by the heat required to raise

water, from the temperature of the room, to superheated steam at the temperature of the escaping gases. The loss due to the heat carried away in the dry chimney gases was found by multiplying the weight of dry gas per pound of combustible by .24 and this by the difference in temperature between the room and the escaping gases. The weight of dry gas per pound of combustible is found by substituting the results of the gas analysis in the following formula:—

$$\frac{11CO_2 + 8O + 7(CO + N)}{3(CO_2 + CO)} \times$$ per cent of carbon in combustible divided by 100.

The loss due to incomplete combustion of carbon is found by substituting the results of the gas analysis in the formula:— $\frac{CO}{CO_2 + CO} \times$ carbon per

pound of combustible × 10150. The last factor (10150) is the heat generated in burning one pound of carbon in carbon monoxide to carbon dioxide. These losses were all reduced to per cents of the total heat per pound of combustible. The above per cents added together and subtracted from 100 give a remainder which consists of the losses due to moisture in the air, radiation etc. Analyses of the furnace gases were made every thirty minutes, in some of the tests, and as the average arrived at may be in error the results of the heat balance do not carry great weight, although they are of interest in locating the division

of the losses. As the calorimeter used was not jacketed or insulated, a dry test was made. All steam outlets from the boiler were closed with the exception of the calorimeter outlet. A slow fire was started under the boiler and the steam pressure gradually raised, and readings of the thermometer and steam gauge taken. For 175 and 200 pounds pressure the calorimeter gave 1.1% of moisture and this was used as a constant for the instrument.

Considerable difficulty was encountered in securing a good grade of coal for the tests. At the time the coal was purchased, it was difficult to get coal of any kind

and still more so to get the
best grades, which were all being
shipped East. The coal used on
the first five tests was purchased
for New River run of mine, but
proved to be a much lower grade
of coal as shown by the analysis
and heating value. It was found
to be from Dingess, West Virginia,
some distance from the New
River district. The analysis and
heating value do not seem to
show what a poor grade the
coal was, as the greatest trouble
arose from the heavy clinker,
that was difficult to remove
when cleaning fires, thus
introducing a large loss.
Tests 6 to 9, inclusive, were
made with anthracite coal

of egg size, and although the heating value was not high it was a good burning coal. The high per cent of ash on these tests was due to the coal bursting and falling through the grates. If a 7/8" bar had been used the per cent of ash would have been less. Tests 10, 11, 12 and 14 were made with Tug River run of mine coal, which had been out in the weather so long and handled so much, that it was almost all slack. This coal is sold for Pocahontas and resembles it but has a lower heating value. No trouble whatever was found in burning this coal. On test No. 13, which was run on Friday, Lick Branch Pocahontas lump

coal was used. From the analysis this appears to be a fine coal but it formed a thin clinker, about ½" thick, that adhered to the bars so strongly that it was impossible to get all of it off, until the grates had cooled down. This clinker closed the air spaces so that it was impossible to force the boiler. Two days were spent in experimenting with different grates, special firing tools and different methods of firing, but the difficulty could not be overcome. None of the coals used were picked or washed for testing purposes but were as sold for ordinary use.

As the tests were made to show the boiler under average

conditions an expert fireman was not employed. Three firemen were watched; a locomotive fireman, a salt water fireman and a lake fireman, each having a different method of firing. The salt water fireman, firing bituminous coal, carried a heavy fire in front and shoved it back at intervals, but the lake fireman spread his coal carefully maintaining a fire of uniform thickness. These firemen fired one door at a time, in rotation, never breaking their order; but the locomotive fireman kept watching his fire, either through the ash or fire door, and fired whenever he saw a spot that needed coal, without regard

to the order of the doors. He kept a thin even fire at all times. The Dingess coal used on the first five tests gave a dense black smoke; the anthracite gave no smoke at all, and the Tug River and Pocahontas coals gave a light yellow smoke. Test No. 5 was of but two hours duration because the supply of coal gave out, the test being made merely to test the blower outfit which proved of insufficient capacity. The blower was tried again in test No. 12 but broke down twice and proved of insufficient capacity. The first twelve tests were run without any air being admitted above the grates, but the last two tests

were made with openings in the fire doors, and the change is noticed in the results of the gas analysis; and had the air been admitted on all the other tests, except when the blower was used, — a slight increase of efficiency would have been the result. A close watch was kept on the water and coal consumption each hour, so that the conditions could be kept as nearly uniform as possible, and very uniform results were obtained.

As the blower was of insufficient capacity the use of a steam jet in the stack became necessary and by its use the various degrees of draft were secured.

No account was taken of the steam used to operate the blower engine or steam jet, as they were both inefficient and their inefficiency should not be laid upon the boiler.

Under these trials the boiler gave no indication whatever of injury; and careful examination shows the boiler to be in just as good condition now as before the tests. It has proved to be a rapid steamer giving practically dry steam at all times. As the result of these tests, and careful observations of the condition and working of the boiler during these tests, I recommend the adoption of this boiler for marine purposes without any alterations in the principles of its design.

J. Rowland Brown,
B.S. in E.E.